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# Estimating *Spartina alterniflora* fractional vegetation cover and aboveground biomass in a coastal wetland using SPOT6 satellite and UAV data

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ABSTRACT

*Spartina alterniflora* (*S. alterniflora*) is one of the most serious invasive species in some coastal wetlands of China, and its fractional vegetation cover (FVC) and aboveground biomass (AGB) are important parameters that affect the ecology of these wetlands. Because of inaccessibility, field surveys are time-consuming, labor intensive, and difficult to implement, especially on a regional scale. Thus, satellite remote sensing and unmanned aerial vehicle (UAV) techniques are the better methods to obtain accurate FVC and AGB information in coastal wetlands. In this study, FVC and AGB of *S. alterniflora* were estimated based on the SPOT6 satellite remote sensing images with 6 m spatial resolution, unmanned aerial vehicle (UAV) images with 0.1 m spatial resolution, over Sansha Bay, a coastal wetland in China. In addition, some field-based samples were also collected. Results showed that most of the FVC ranged from 40% to 80%, indicated a medium-high and high level; while AGB varied from 0 to 15 kg $m^{-2}$. Spatial distribution pattern of FVC and AGB were mainly influenced by the ecological and geographical environment. Meanwhile, the local distribution characteristics in the near-shore area also had close relation with anthropogenic activities. Accuracy analysis showed that, the root mean square errors (RMSE) of FVC and AGB were 0.108 and 0.415, and the coefficients of determination ($R^2$) were 0.905 and 0.898, respectively. The results suggest that it is feasible and effective to estimate FVC and AGB of *S. alterniflora* in coastal wetland using SPOT and UAV data with high accuracy.

## 1. Introduction

*Spartina alterniflora*, which is native to the Atlantic and Gulf coasts of North America, is a perennial and deep-rooted salt marsh grass that has been expanding rapidly outside its original area owing to intentional or unintentional human introduction. *S. alterniflora* forms a monospecific community that threatens native ecosystems, encroaches on the habitats of indigenous communities, and causes decreases in native species richness (Chen et al., 2012). *S. alterniflora* was intentionally introduced into China in 1979 for sediment stabilization and dike protection and has continuously replaced native plants such as mangrove forests and *Phragmites communis* or invaded bare mudflats in the coastal marsh along the eastern and southeastern coasts of China (Xiang et al., 2015; Yin et al., 2015). *S. alterniflora* invasion is considered one of the greatest threats to Chinese coastal wetlands.

Fractional vegetation cover (FVC) is generally defined as the ratio of the vertical projection area of vegetation (including leaves, stalks, and branches) on the ground to the total vegetation area (Jia et al., 2015). The FVC is an important surface property expressing the vegetation coverage status on the ground (Jing et al., 2011). It is also a sensitive indicator for evaluating land degradation and desertification (Wang et al., 2002) and is a controlling factor in the universal soil-loss equation and revised universal soil-loss equation and numerical climate and hydro-ecological models (Sellers et al., 1996; Marticorena et al., 1997). To date, the FVC has been extensively used in applications of agriculture, soil erosion risk evaluation, drought monitoring, environmental assessment, and some other related studies (Gutman and Ignatov, 1998; Matsui et al., 2005; Zhang et al., 2010). Aboveground biomass (AGB) is an important part of biomass. Due to the difficulty of belowground biomass field data collection, attention is often focused on aboveground biomass (Güneralp et al., 2014). AGB is an essential biophysical parameter for estimating the growth trend and ecosystem services of vegetation, such as grass forage availability, herbivore carrying capacity (Mutanga and Skidmore, 2004; Yahdjian and Sala, 2006), and forest carbon storage or emission in the global carbon cycle (Rojas-Garcia et al., 2015; Næsset et al., 2016). The AGB can thus provide critical information for quantifying the amount of sequestered carbon, guiding sustainable grassland/forest management, estimating the productivity of ecosystems, and creating greenhouse gas inventories (Lu, 2006; Tian et al., 2012). Therefore, timely and accurate monitoring

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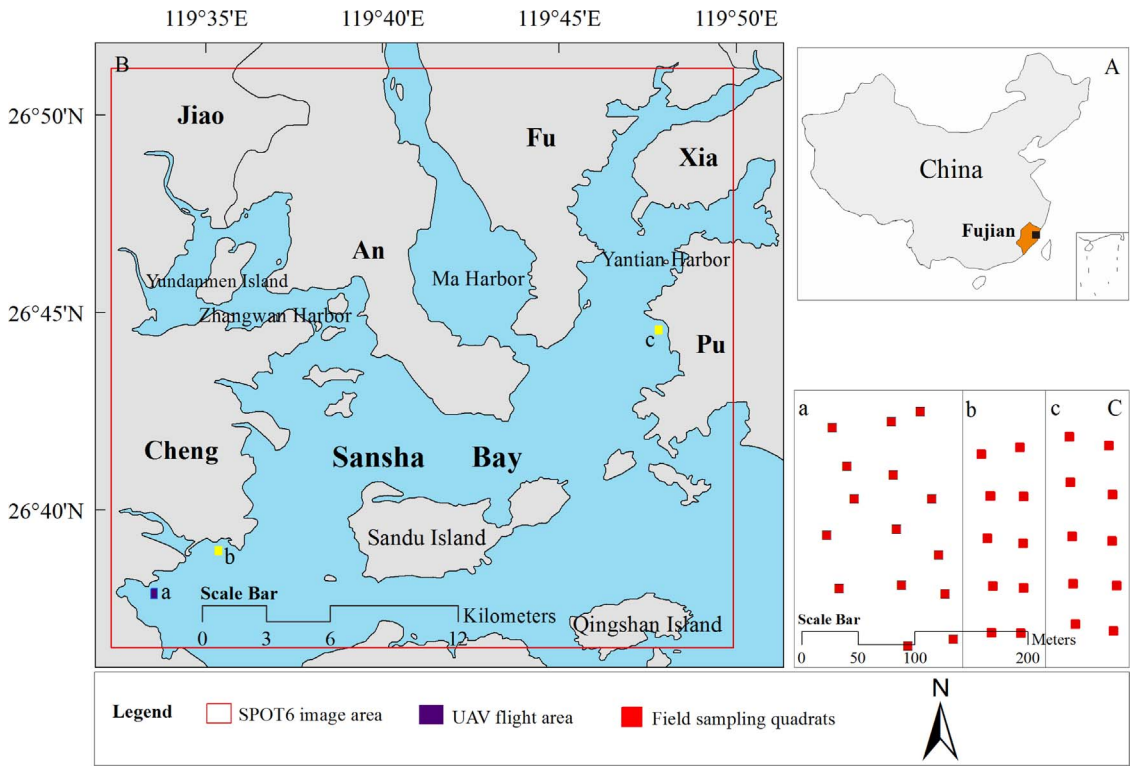


**Fig. 1.** The study area location (A), satellite and UAV area of Sansha Bay (B), and field sampling quadrats (C).

of the FVC and AGB in an ecosystem can not only show the growth status of local vegetation but also provide evidences, those ecosystem managers and scientists can use to evaluate the effects of ecological restoration, as well as to study global changes and realize sustainable ecosystem development.

Field-based sample surveys including field digital cameras have traditionally been used to provide vegetation FVC and AGB estimates over time, but this method is time-consuming, cost-prohibitive, labor intensive, and infeasible due to inaccessibility. Moreover, this method cannot provide the spatial distribution of vegetation information for large areas (Rana et al., 2016). Satellite remote sensing offers a more effective means of collecting regional and global data in a continuous spatio-temporal context (Moreau et al., 2003). Remotely sensed data thus play a fundamental role in the acquisition of regional surface parameters. Remote sensing has become the primary source for such information and has been widely used to estimate FVC and AGB, particularly at a regional scale (Li et al., 2016; Jia et al., 2016). Methods for retrieving the FVC using remotely sensed data have been developed, and the main ones include the empirical model (Patel et al., 2007), vegetation index (Jakubauskas et al., 2000), sub-pixel unmixing models (Gutman and Ignatov, 1998), and linear spectral mixture models (Theseira et al., 2002). Jiapaer et al. (2011) further compared these methods and revealed different accuracies in different sensitive conditions. The empirical models can produce good results for particular areas and are highly dependent on the specified in situ measurements. A vegetation index such as the NDVI (Normalized Difference Vegetation Index) provides a simple and effective solution to FVC estimation. The spectral mixture approach is suitable for the coverage of sparse desert vegetation. Therefore, a sub-pixel unmixing model based on finely detailed vegetation maps can yield a high precision. Remote sensing allows estimating the AGB over wide geographical extents and overcoming the problems of field data underrepresentation and mainly involves optical remote sensing and radar systems (Saatchi et al., 2007; Zhang et al., 2014). Optical remote sensing indirectly derives the AGB through empirical relationships between the reflectance or spectral indices and canopy parameters (Li et al., 2012). However, radar system backscatter saturation is a distinct limitation of radar for estimating the AGB in high biomass regions (LeToan et al., 2004). For the ground data acquisition techniques, unmanned aerial vehicles (UAV) have undergone a remarkable development in recent years, fly at low altitudes, and obtain ultra-high spatial resolution images at a low operational cost. They are an important complement to satellite remote sensing and are now powerful sensor-bearing platforms for various agricultural, ecological, and environmental applications (Hardin and Hardin, 2010; Xiang and Tian, 2011; Vega et al., 2015).

Several studies have paid a great deal of attention to wetland vegetation, some biophysical parameters such as the FVC, AGB, and others were obtained. However, the techniques were mainly based on satellite remote sensing and field sampling surveys. Jachowski et al. (2013) assessed the mangrove forest biomass in Southwest Thailand using GeoEye-1 satellite imagery and field-based measurements. Ghosh et al. (2016) measured some biophysical parameters such as the FVC, AGB, and the canopy-level chlorophyll content (CHL) in tidal wetlands of the northern Gulf of Mexico using a combination of ground data and MODIS images. In this study, SPOT6 satellite and UAV data combined with the field sampling data were used to estimate the FVC and AGB of *S. alterniflora* in Sansha Bay, a coastal wetland of China, to understand the two biophysical parameters' spatial distribution and to provide a reference for coastal wetland ecosystem research and management.

## 2. Materials and methods

### 2.1. Description of the study area

Sansha Bay is a semi-closed harbor with a winding coastline, a broad and plain tidal flat, and abundant ecological resources; it is surrounded by Xiapu and Fuan counties, and the Jiaocheng district, located in the east of Fujian Province, Southeast China (Fig. 1). The tidal marsh habitats are mostly dominated by the alien species *S. alterniflora*, native mangroves, and *Phragmites australis*. Several other salt-resistant plants are also encountered, such as *Tamarix chinensis* Lour. and *Suaeda salsa*. The highly saline and anoxic nature of the soil inhibits